Method For Estimating The Catapult Performance Of A Carrier-Based Airplane

17 May 1963

Prepared under Navy, Bureau of Naval Weapons
Contract NOw 62-0197-t
Task Order No. 62-1

Final Report
Report No. 2-53470/3R459

DEPARTMENT OF THE NAVY ★ BUREAU OF NAVAL WEAPONS

LTV VOUGHT AERONAUTICS DIVISION
LTV AEROSPACE CORPORATION

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FOREWORD

This study was sponsored by the Aerodynamics and Hydrodynamics Branch of the Airframe Design Division, Bureau of Naval Weapons, Department of the Navy under Contract NOw 61-0197-t, Task Order No. 62-1. Contained in this report is a method for estimating the catapult performance of a carrier-based airplane. The technical monitor has been Mr. R. E. Jaquis.

ABSTRACT

A simplified method for predicting the catapult performance of a carrier-based airplane has been developed under Contract No. NOw 62-0197-t, Task Order No. 62-1, for the Bureau of Naval Weapons. The method consists of two parts; (a) the determination of airplane position at the end of the catapult power stroke and (b) the determination of the motion of the airplane subsequent to leaving the catapult. The method is oriented toward use of a small digital computer; however, the calculations could be performed with only the use of a desk calculator.

TABLE OF CONTENTS

REFERENCES

(a) Contract NOw 62-0197-t; Task Order No. 62-1, Development of a Method for Assessing Catapult Performance of Carrier Based Aircraft

(b) CVA Report No. ElR-13135, Development of a Simplified Method for Assessing Symmetrical Catapult Performance of Carrier Aircraft, 19 May 1961

(c) Naval Air Engineering Facility (SI) Report No. NAEF 06900, Aircraft Carrier Reference Data Manual, dtd 1 July 1957, Revised 1 June 1961

(d) BuWeps Sketch RSSH-1338, Steam Catapult Capacity, Applicable Revision as Dated.

INTRODUCTION

The necessity for a carrier based airplane to be launched from the carrier deck defines a major requirement for the airplane. This is a very complex requirement which affects the entire airplane design. The assessment of the capability of a particular airplane design to perform this maneuver in an acceptable manner is not a simple task, Although there are numerous effects with which the airplane catapulting capability can be measured, one of the major aspects of a launch that constitutes a useful basis for measurement is the tendency of the airplane to sink over the bow of the carrier after leaving the carrier deck. A short, easy-to-use method for determining the amount of sink over the bow would be of great assistance in assessing the catapulting capability of a new airplane design. Consequently, a research and development program was instituted under reference (a) for the purpose of developing a simplified method of assessing catapult performance, as outlined in reference (b).

This program has resulted in the development of a set of simplified equations of motion that can be used to determine the motion of the airplane subsequent to the end of the catapult power stroke, and of an iteration procedure for determining the airplane displacement and rate conditions at the end of the catapult power-stroke, which become the initial conditions for the equations of motion. A procedure for determining the catapult force is presented as a part of the iteration procedure.

The equations of motion were originally written in the ground reference system, but this was subsequently changed to the wind axis system, since most of the solution time occurs after the airplane leaves the deck. Provisions

are made, however, for maintaining the location of the aircraft in the ground reference system.

In this simplified mathematical model the rigid landing gears are represented by non-linear tire springs and shock strut air springs. The unsprung masses of the gears are considered to be massless and hence do not appear in the equations. Since the hydraulic metering characteristics of the shock struts may not always be available for this analysis, this damping function has been eliminated from the model. However, since the extension damping forces in the landing gear contribute significantly to the motion of the airplane between the end of the catapult stroke and deck edge, the effect of the extension damping is included by the use of an "attenuation factor". This factor is an empirically determined number that accounts for the reduction of static gear load during the gear extension cycle.

Although the method presented herein is considerably less complex than the more sophisticated procedures frequently used with aircraft whose characteristics are completely defined, this method should provide a good estimate of the carrier catapult performance characteristics of the aircraft.

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	A10	Distance from main gear to c.g. in ground X direction	ft.	
	A11	Distance from nose gear to c.g. in ground X direction	ft.	
	ALFA	Angle of attack	degrees	
	ALFADT	Angle of attack table associated with drag coefficients	degrees	
	ALFALT	Angle of attack table associated with lift coefficients	degrees	
	ALFAMT	Angle of attack table associated with aero moment coefficients	degrees	
	ALIFT	Airplane aerodynamic lift	lbs.	+Up
	AM	Airplane mass	slugs	
	AMEDGE	Distance from main gear at end of catapult stroke to deck edge	ft.	
	AMOM	Airplane aerodynamic moment about c.g.	ft. lbs.	+Nose Up
	ANEDGE	Distance from nose gear at end of catapult stroke to deck edge	ft.	

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	APIYY	Airplane pitch moment of inertia at c.g.	slug-ft^2	
β	BETA	Catapult bridle angle with ground	degrees	
	CBAR	Mean geometric chord	ft.	
	CDT	Drag coefficient table associated with angle of attack	none	
	CLT	Lift coefficient table associated with angle of attack	none	
	CMT	Aero moment coefficient table associated with angle of attack	none	
	D1	Distance from nose gear to c.g. in fuselage X direction	ft.	
	D2	Distance from c.g. to bridle attach point in fuselage X direction	ft.	
	D3	Distance from c.g. to main gear in fuselage X direction	ft.	
	D6	Distance from c.g. to nose axle fully extended in fuselage Z direction	ft.	
	D6BAR	Distance from c.g. to nose axle in fuselage Z direction	ft.	
	D7	Distance from c.g. to bridle attach point in fuselage Z direction	ft.	

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	D8	Distance from c.g. to main axle fully extended in fuselage Z direction	ft.	
	D8BAR	Distance from c.g. to main axle in fuselage Z direction	ft.	
	D12	Catapult bridle length	ft.	
	D17	Distance from c.g. to aero. ref. point in fuselage X direction	ft.	
	DEDGE	Distance from catapult shuttle at end of stroke to deck edge	ft.	
	DELT	Time increment	sec.	
	DELT1	Time increment before deck edge	sec.	
	DELT2	Time increment after deck edge	sec.	
	DRAG	Airplane aerodynamic drag	lbs.	
	FC	Catapult force at stroke end	lbs.	
γ	GAMA	Flight path angle	degrees	+Up
$\dot{\gamma}$	GAMDØT	Rate of change of flight path angle	rad./sec	
	KID	Control number if KID = 0 cat. bridle attach point stationary: if KID > 0 cat. bridle attach point moves with nose gear stroke	none	

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	PK	Aerodynamic pitch damp-coefficient	$lb.sec^2$	-Always
	PM, PMA	Main gear load	lbs.	
	PMK	Main gear load attenuation constant	none	
	PMT	Main gear load table associated with axle strokes	lbs.	
	PMTT	Main gear load table associated with main gear	lbs.	
	PN, PNA	Nose gear load	lbs.	+Up
	PNK	Nose gear load attenuation constant	none	
	PNT	Nose gear load table associated with axle strokes	lbs.	
	PNTT	Nose gear load table associated with nose gear tire deflection	lbs.	
ρ	RHO	Air density	$\frac{slugs}{ft.^3}$	
	RMO	Main gear undeflected tire radius	in.	
	RNO	Main gear undeflected tire radius	in.	
	S	Wing area	$ft.^2$	
σ_T	SIGT	Thrust angle	degrees	+Up

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	SM	Main gear axle stroke	ft.	+Compressed
	SMI	Main gear axle stroke	in.	
	SMT	Main gear axle stroke table associated with main gear load	in.	
	SN	Nose gear axle stroke	ft.	+Compressed
	SNI	Nose gear axle stroke	in.	
	SNT	Nose gear axle stroke table associated with main gear load	in.	
$\sum F_x$	SUMFX	Summation of forces in X direction	lbs.	+Forward
$\sum F_z$	SUMFZ	Summation of forces in Z direction	lbs.	+Up
$\sum M_y$	SUMMY	Summation of moments about Y axis	ft.lbs.	+Nose Up
t	T	Time	sec.	
	TARM	Thrust moment arm to c.g.	ft.	+Above c.g.
θ	TH	Aircraft pitch angle	degrees	+Nose Up
$\ddot{\theta}$	THDDØT	Aircraft pitch acceleration	rad/sec^2	
$\dot{\theta}$	THDØT	Aircraft pitch velocity	rad/sec	
	TIRMT	Main gear tire deflection table associated with main gear load	in.	

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DIRECTION	UNITS	SENSE
	TIRNT	Nose gear tire deflection table associated with nose gear load	in.	
	TMAX	Maximum time to run problem	sec.	
	TR	Airplane thrust	lbs.	+Forward
	UR	Coefficient of rolling friction	none	
	V	Airspeed	ft./sec.	+Forward
$\dot{V}$	VDOT	Airplane c.g. acceleration in wind axes	ft./sec.	
	VX	X component of V in ground axes	ft./sec.	
	VZ	Z component of V in ground axes	ft./sec.	
	W	Airplane weight	lbs.	
	WIND	Wind velocity with respect to ground	ft./sec.	+Headwind
	X	Horizontal ground position	ft.	+Forward
	XB	Fuselage station of catapult attachment point	F.S.	
	XCG	Fuselage station of airplane c.g.	F.S.	
$\dot{X}$	XDOT	Ground speed	ft./sec.	

DEFINITION OF SYMBOLS

SYMBOL	FORTRAN NAME	DEFINITION	UNITS	SENSE
	XL	Fuselage station of aerodynamic reference point	F.S.	
	XM	Fuselage station of main gear axle	F.S.	
	XN	Fuselage station of nose gear axle	F.S.	
	Z	Vertical height of c.g. above deck	ft.	+Above Deck
	ZB	Waterline of catapult bridle attach point (at nose stroke = 0 if applicable)	w.l.	
	ZCG	Waterline of airplane c.g.	w.l.	
	ZM	Waterline of main gear axle at zero stroke	w.l.	
	ZN	Waterline of nose gear axle at zero stroke	w.l.	

1. An angle name with R added is the angle in radians
2. Fuselage stations must increase aft
3. Waterlines must increase up
4. If no symbol is given it is the same as the FORTRAN NAME

Deck

SECTION 1

METHOD OF ESTIMATING THE CATAPULT PERFORMANCE OF A CARRIER BASED AIRPLANE

Section 1.1 Introductory Information

A simplified method for estimating the catapult performance of an airplane for a symmetrical launch is presented in this section. The method is presented in such a manner that it may be accomplished by following the step by step directions using only a desk calculator. The same procedure is also coded in FORTRAN II for utilization of a digital computer. The procedure consists of two distinct parts;

1) determination of conditions at the end of the catapult stroke, and
2) determination of airplane motion subsequent to catapult release.

Certain assumptions are necessary to bring this problem into the realm of small (8K) digital computers or possible hand calculation. The basic assumptions are:

1) Three degrees of freedom are considered for airplane motion; horizontal translation, vertical translation, and pitch.
2) Rigid body motion only is considered for the airplane.
3) The landing gear arrangement is of the tricycle type.
4) The main and nose gear stroking parts are massless.
5) The main and nose gear stroke perpendicularly to the airplane reference line.
6) The thrust is constant.

7) The tail setting is constant.

8) At the end of the catapult stroke the airplane pitch rate, pitch acceleration, vertical translational rate, and vertical translational acceleration are zero.

Section 1.2 Preliminary Calculations for Machine Computation

Preliminary calculations are necessary to define the horizontal force in the catapult at the end of the power stroke (just prior to contact of the brake). An end speed appropriate to the weight being considered and consistent with reference (d) is chosen. The incremental end speed due to airplane thrust and drag is calculated according to reference (c). For the C-7 catapult

$$V_{ET} = \left[\dot{X}^2 + \frac{5640\,(T_A - D_A)}{W + 4000} \right]^{1/2} - \dot{X}$$

where $\dot{X}$ = deadload endspeed, knots

T_A = average thrust of airplane during power stroke, pounds

D_A = average drag of airplane during power stroke, pounds

V_{ET} = endspeed increment, knots

It has been observed for a wide range of conditions that the average drag, D_A, is approximately 60% of the drag force occuring at the end of the power stroke.

The catapult force at the end of the power stroke can be determined from

$$F_c = \left[\frac{1 - \frac{1}{2}(P/M)}{S}\right] M \dot{X}^2$$

where F_c = catapult horizontal force at end of power stroke, pounds

P/M = peak to mean ratio for the catapult

S = catapult power stroke, feet

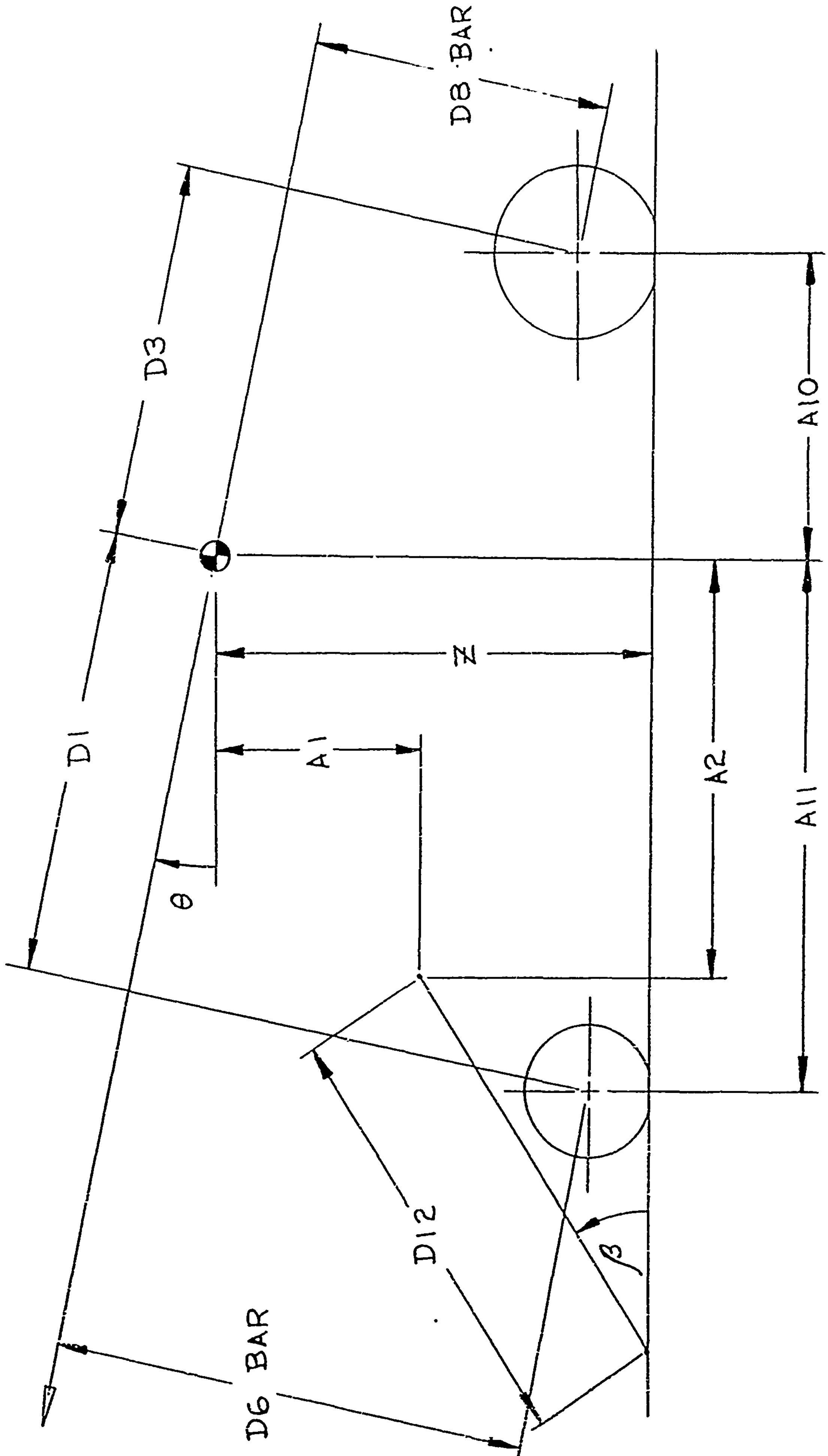
M = airplane mass, slugs

$\dot{X}$ = deadload endspeed, feet per second

The gear attenuation constants PNK and PMK must be determined in the initial phase of calculations. The constants are defined as

$$\text{PNK, PMK} = 1 - \frac{\text{Average Reverse Damping Load}}{\text{Air Spring Load}}$$

Since the shock struts will be unloading during the deck run this problem is only concerned with the reverse damping characteristics of the struts. For the F-8 airplane it was found that attenuation factors from .8 to .9 gave results that agreed with those obtained by more scphisticated methods. It is recommended that in the absence of any data that a value in the range of .8 to .9 be used. If it is known that a mechanical device is present in the gear to provide additional orifice area for reverse stroking then a value between .95 and 1.00 is recommended for the attenuation factors.



Airplane Geometry

Figure 1

Section 1.3 Preliminary Calculations for Hand Computation

If the equations of Section 2 and Section 3 are to be solved by hand the following constants will be required in addition to those defined in Section 1.2.

$$D17 = (XCG - XL)/12$$
$$D1 = (XCG - XN)/12$$
$$D3 = (XM - XCG)/12$$
$$D6 = (ZCG - ZN)/12$$
$$D8 = (ZCG - ZM)/12$$
$$D2 = (XCG - XB)/12$$

If the bridle is attached to a fixed point on the airplane D7 is constant.

$$D7 = (ZCG - ZB)/12.$$

If the bridle attachment point moves with nose gear stroke D7 must be calculated each pass through Section 2 and is

$$D7 = (ZCG - ZB - SN)/12.$$

SECTION 2

DETERMINATION OF CONDITIONS AT THE END OF THE CATAPULT STROKE

The procedure for determining the airplane position at the end of the catapult power stroke is presented in this section. It may be followed in a step by step manner for hand calculation. From assumption 8 in Section 1.1 we may write

$$\sum F_z = 0$$

and

$$\sum M_y = 0$$

These two equations may be written such that the only unknowns appearing are PM and PN. An iteration procedure is used to find the PM and PN that satisfy both of these equations. The iteration procedure is carried out in the following manner (The FORTRAN routine does this at the beginning and uses the statements down to and including 13)

1. Estimate gear loads

   PM = .75W

   PN = PM/5

2. Obtain gear strokes SM and SN from gear load-stroke tables.
3. Obtain tire deflections TIRM and TIRN from tire load-stroke tables and calculate rolling radii

$$RM = RMO - TIRM$$
$$RN = RNO - TIRN$$

4. Calculate

$$R = RN - RM$$
$$Q = (D8 - SM) - (D6 - SN)$$
$$P = D1 + D3$$

5. From Figure 2, triangle ABC yields the following equation

$$\sin\Theta = \frac{P \cdot R + \sqrt{(P \cdot R)^2 + (Q^2 - R^2)(P^2 + Q^2)}}{P^2 + Q^2}$$

Solve for θ

6. Calculate c.g. height z

$$Z1 = (D6 - SN)\cos\Theta - D1\sin\Theta + RN$$
$$Z2 = (D8 - SM)\cos\Theta + D3\sin\Theta + RM$$
$$Z = \frac{1}{2}(Z1 + Z2)$$

7. Calculate instantaneous gear lengths

$$D8BAR = (Z - D3\sin\Theta - RM)/\cos\Theta$$
$$D6BAR = (Z + D1\sin\Theta - RN)/\cos\Theta$$

8. Calculate vertical distance from c.g. to bridle attach point

$$A1 = D7\cos\Theta - D2\sin\Theta$$

9. Calculate horizontal distances from c.g. to main and nose axles

$$A10 = D3\cos\Theta - D8BAR\sin\Theta$$
$$A11 = D1\cos\Theta + D6BAR\sin\Theta$$

10. Obtain aerodynamic coefficients CL and CM from aero tables ($\alpha = \theta$)

11. Calculate aerodynamic lift and moment

$$ALIFT = \frac{1}{2}\rho S V^2 C_L$$
$$AMOM = \frac{1}{2}\rho S V^2 (CBAR) C_M + D17 \cdot ALIFT \cdot \cos\Theta$$

12. Calculate bridle angle

$$\beta = (Z - A1)/D12$$

13. Calculate vertical component of catapult force

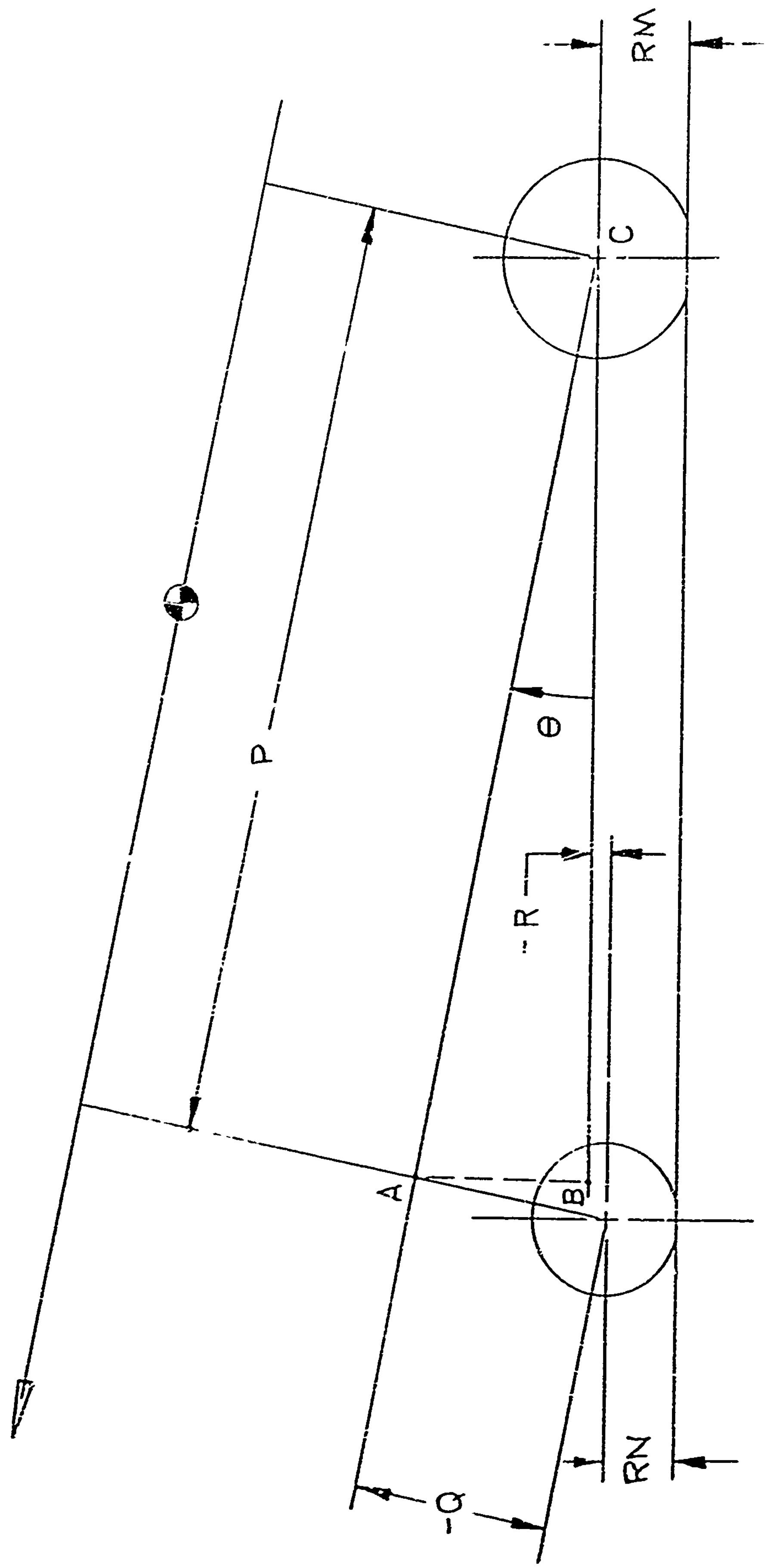
$$FCZ = FC\tan\beta$$

14. Calculate catapult force along bridle

$$FCP = FC/\cos\beta$$

15. Calculate perpendicular distance from cg to catapult force line of action

$$PCBAR = D7 \cdot \cos(\Theta + \beta) - D2 \cdot \sin(\Theta + \beta)$$



Airplane Geometry Used in Calculating Airplane Attitude

Figure 2

16. Calculate sum of vertical forces (neglecting gear forces)

$$\sum F_Z = -W + ALIFT + TR \cdot \sin(\theta + \sigma_T) - FCZ$$

17. Calculate sum of moments about y axis (neglecting vertical gear forces)

$$\sum M_y = AMOM + PCBAR \cdot FCP - Z \cdot UR \cdot (2P_M \cdot P_N) - TR \cdot TARM$$

18. Calculate nose gear load

$$PNA = \frac{-\left(\sum M_y + A10 \cdot \sum F_Z\right)}{A10 + A11}$$

19. Calculate main gear load

$$PMA = \frac{\sum M_y - A11 \cdot \sum F_Z}{2\,(A10 + A11)}$$

20. If PMA and PNA both check to within 5% of PM and PN respectively continue to part II. If not calculate

$$PN = \frac{1}{2}(PN + PNA)$$
$$PM = \frac{1}{2}(PM + PMA)$$

Go back to statement 2 and continue.

SECTION 3

DETERMINATION OF AIRPLANE MOTION SUBSEQUENT TO CATAPULT RELEASE

With the initial conditions established by Section 2 the three equations of motion

$$\dot{V} = 1/AM \sum F_x$$
$$\dot{\gamma} = 1/AM \cdot V \sum F_z$$
$$\ddot{\theta} = 1/APIYY \sum M_y$$

in the wind axis system may be numerically integrated to give time histories of the airplane velocity and position. This procedure is straight forward with the exception that the gear loads are set to zero when they pass over the deck edge.

The step by step procedure is as follows:

1. Calculate horizontal distance from c.g. to bridle attachment point

$$AZ = DZ \cos\theta + D7 \sin\theta$$

2. Calculate horizontal distance from nose gear to deck edge with airplane at end of catapult stroke

$$ANEDGE = DEDGE + AZ + D12 \cos\beta - A11$$

3. Calculate horizontal distance from main gear to deck edge with airplane at end of catapult stroke

$$AMEDGE = ANEDGE + A10 + A11$$

4. Establish initial conditions

$$\dot{\gamma} = 0$$
$$\gamma = 0$$
$$\alpha = \theta$$
$$\dot{z} = 0$$
$$\dot{\theta} = 0$$
$$X = 0$$
$$V = \dot{X} + WIND$$
$$T = 0$$

5. Obtain nose tire deflection TIRN from load-stroke table

6. Calculate rolling radius of nose tire

$$RN = (RNO - TIRN)/12$$

7. Calculate instantaneous length of nose gear (see figure 2)

$$D6BAR = (Z + D1 \sin\theta - R_N)/\cos\theta$$

8. Calculate nose gear stroke

$$SN = D6 - D6BAR$$

9. If SN > 0 go to next step

If SN ≤ 0 set PN = 0 go to step 11

10. Obtain nose gear load PN from gear load stroke table

11. Obtain main tire deflection TIRM from load-stroke table

12. Calculate rolling radius of main tire

$$RM = (RMO - TIRM)/12$$

13. Calculate instantaneous length of main gear (see figure 2)

$$D8BAR = (Z - D3 \sin\theta - RM)/\cos\theta$$

14. Calculate main gear stroke

$$SM = D8 - D8BAR$$

15. If SM > 0 go to next step

If SM ≤ 0 set PM = 0 go to step 17

16. Obtain main gear load PM from gear load stroke table

17. Calculate distances

$$A10 = D3 \cos\theta - D8BAR \sin\theta$$
$$A11 = D1 \cos\theta + D6BAR \sin\theta$$

18. Obtain aerodynamic coefficients CL, CD, and CM from aero tables

19. Calculate aerodynamic loads

$$ALIFT = \frac{1}{2}\rho S V^2 C_L$$
$$DRAG = \frac{1}{2}\rho S V^2 C_D$$
$$AMOM = \frac{1}{2}\rho S V^2 (CBAR) C_M + D17 \cdot ALIFT \cdot \cos\alpha$$

20. Calculate sum of forces in x direction

$$\sum F_X = TR\cos(\alpha + \sigma_T) - DRAG - W\sin\gamma + PN \cdot PNK \cdot (\sin\gamma - UR \cdot \cos\gamma) + 2PM \cdot PMK \cdot (\sin\gamma - UR\cos\gamma)$$

21. Calculate sum of forces in z direction

$$\sum F_Z = ALIFT - W\cos\gamma + TR\sin(\alpha + \sigma_T) + PN \cdot PNK \cdot (\cos\gamma + UR\sin\gamma) + 2PM \cdot PMK \cdot (\cos\gamma + UR\sin\gamma)$$

22. Calculate sum of moments about y axis

$$\sum M_Y = AMOM - TR \cdot TARM + PK \cdot \dot{\theta} \cdot V + PN \cdot PNK \cdot (A11 - UR \cdot Z) - 2PM \cdot PMK \cdot (A10 + UR \cdot Z)$$

23.
$$\dot{V} = \frac{1}{AM} \sum F_X$$
$$V = V + \dot{V}\Delta t$$
$$\dot{\gamma} = \frac{1}{V \cdot AM} \sum F_Z$$
$$\gamma = \gamma + \dot{\gamma}\Delta t$$
$$\ddot{\theta} = \frac{1}{I_{YY}} \sum M_Y$$
$$\theta = \theta + \dot{\theta}\Delta t + \frac{1}{2}\ddot{\theta}\Delta t^2$$
$$\dot{\theta} = \dot{\theta} + \ddot{\theta}\Delta t$$

24. Calculate angle of attack

$$\alpha = \theta - \gamma$$

25. Calculate components of V in ground axes

$$V_X = V\cos\gamma$$
$$V_Z = V\sin\gamma$$

26 Calculate ground speed

$$\dot{X} = V_X - WIND$$

27. Calculate position in ground coordinates

$$X = X + \dot{X}\Delta t$$
$$Z = Z + V_Z\Delta t$$

28. For 3 conditions

A. Both gears on deck go to 5

B. Main gear only on deck set PN = 0, go to 11

C. Both gears off deck set PN = PM = 0, go to 18

Continue above procedure until tmax is reached

SECTION 4

CONCLUDING REMARKS

The program presented in this report is in part based upon empirical data; therefore, it will be very helpful to future users of the method to obtain and incorporate additional data and to improve the accuracy of the empirical quantities.

If an airplane is or becomes marginal in terms of sink over the bow, almost any factor which affects the airplane motion in any way will have an effect on the amount of sink. Any very small changes in static margin, in gear load characteristics, in thrust available, or other such characteristics, can cause considerable differences in amount of sink experienced by the airplane. The procedure given in this report should indicate those areas which deserve the most attention with regard to improving the carrier suitability of the airplane.

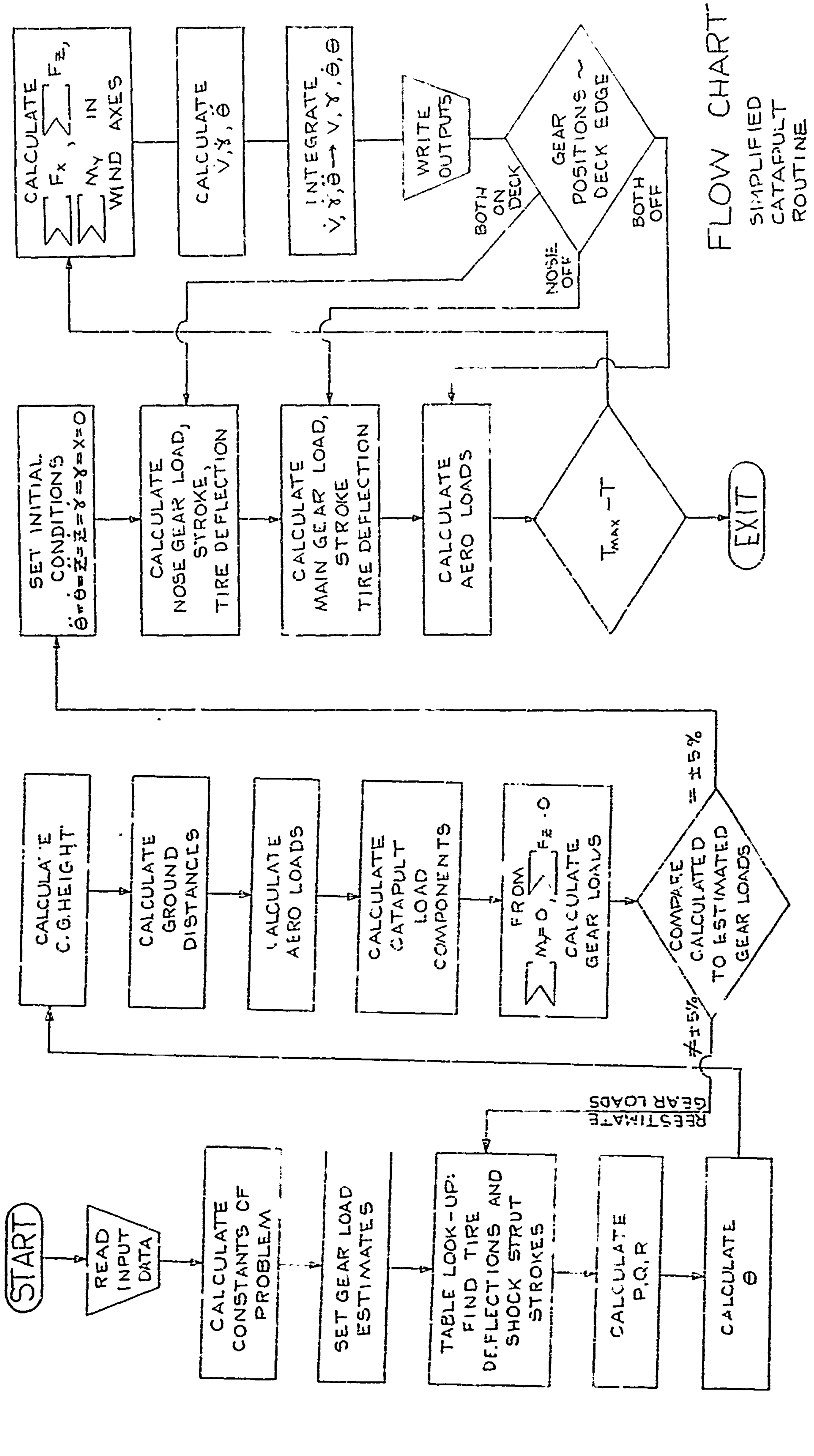
APPENDIX A

FORTRAN ROUTINE FOR MACHINE COMPUTATION

This appendix includes a flow chart of the routine, a source listing of the routine, a format for the input data, and a definition of the output data.

CS,

```
C     AIRPLANE BALANCE AND FLY... PER SIMPLIFIED CATAPULT REPORT
      SUBROUTINE STABLE (Y1,X1,N, ...,FUN)
      DIMENSION X1(10),Y1(10)
      NN=N
 5    DO 15 I=1,NN
 10   IF(X1(I)-XARG) 15,20,20
 15   CONTINUE
 16   I=NN
 20   IF (I-1) 25,25,30
 25   I=2
 30   SLOPE=(Y1(I)-Y1(I-1))/(X1(I)-X1(I-1))
 35   FUN=SLOPE*(XARG-X1(I-1))+Y1(I-1)
 50   RETURN
      END
C     SIMPLIFIED CATAPULT ROUTINE
      DIMENSION PMT(10),SMT(10),PNT(10),SNT(10),PMTT(10),TIRMT(10),
     1PNTT(10),TIRNT(10),ALFALT(10),CLT(10),ALFAMT(10),CMT(10),
     2ALFADT(10),CDT(10),TITLE(12)
      READ INPUT TAPE 5,88,TITLE
      READ INPUT TAPE5, 99,(PMT(I),I=1,10),(SMT(I),I=1,10)
      READ INPUT TAPE5, 99,(PNT(I),I=1,10),(SNT(I),I=1,10)
      READ INPUT TAPE5, 99,(PMTT(I),I=1,10),(TIRMT(I),I=1,10)
      READ INPUT TAPE5, 99,(PNTT(I),I=1,10),(TIRNT(I),I=1,10)
      READ INPUT TAPE5, 99,(ALFALT(I),I=1,10),(CLT(I),I=1,10)
      READ INPUT TAPE5, 99,(ALFADT(I),I=1,10),(CDT(I),I=1,10)
      READ INPUT TAPE5, 99,(ALFAMT(I),I=1,10),(CMT(I),I=1,10)
 100  READ INPUT TAPE5,
     1 99,XCG,ZCG,XN,ZN,XM,ZM,YB,ZB,XL,RNO,RMO,RHO,S,CBAR,
     1D12,FC,TR,W,UR,TARM,XDOT,APIYY,SIGT,PNK,PMK,PK,DELT1,
     2DELT2,WIND,DEDGF,TMAX
      READ INPUT TAPE5, 97,KIO
 79   FORMAT(5E15.4)
 80   FORMAT(1H0,3X,27HMAIN GEAR LOAD STROKE TABLE//)
 81   FORMAT(1H0,3X,27HNOSE GEAR LOAD STROKE TABLE//)
 82   FORMAT(1H0,3X,27HMAIN TIRE LOAD STROKE TABLE//)
 83   FORMAT(1H0,3X,27HNOSE TIRE LOAD STROKE TABLE//)
 84   FORMAT(1H0,3X,15HAERO LIFT TABLE//)
 85   FORMAT(1H0,3X,15HAERO DRAG TABLE//)
 86   FORMAT(1H0,3X,18HAERO  MOMENT TABLE//)
 87   FORMAT(1H0,3X,12HGENERAL DATA//)
 88   FORMAT(12A6)
 89   FORMAT(1H1)
 95   FORMAT(19HA/C DID NOT BALANCE)
 96   FORMAT(7E15.4,F15.3)
 97   FORMAT (I3)
 98   FORMAT(//9X,1HZ,11X,5HTHETA,11X,5HGAMMA,13X,2HPM,13X,2HPN,
```



FLOW CHART
SIMPLIFIED CATAPULT ROUTINE

```
     114X,1HX,12X,3HVEL,11X,4HTIMF/)
99    FORMAT (5E10.4)
      WRITE OUTPUT TAPE 6,89
      WRITE OUTPUT TAPE 6,88,TITLE
      WRITE OUTPUT TAPE 6,80
      WRITE OUTPUT TAPE 6,79,PMT,SMT
      WRITE OUTPUT TAPE 6,81
      WRITE OUTPUT TAPE 6,79,PNT,SNT
      WRITE OUTPUT TAPE 6,82
      WRITE OUTPUT TAPE 6,79,PMTT,TIRMT
      WRITE OUTPUT TAPE 6,83
      WRITE OUTPUT TAPE 6,79,PNTT,TIRNT
      WRITE OUTPUT TAPE 6,84
      WRITE OUTPUT TAPE 6,79,ALFALT,CLT
      WRITE OUTPUT TAPE 6,85
      WRITE OUTPUT TAPE 6,79,ALFADT,CDT
      WRITE OUTPUT TAPE 6,86
      WRITE OUTPUT TAPE 6,79,ALFAMT,CMT
      WRITE OUTPUT TAPE 6,87
      WRITEOUTPUTTAPE6,79,XCG,ZCG,XN,ZN,XM,ZM,XB,
     1ZB,XL,RNO,RMO,RHO,S,CBAR,
     1D12,FC,TR,W,UR,TARM,XDOT,APIYY,SIGT,PNK,PMK,PK,DELT1,
     2DELT2,WIND,DEDGE,TMAX
      WRITE OUTPUT TAPE 6,97,KID
      WRITE OUTPUT TAPE 6,89
      WRITE OUTPUT TAPE 6,88,TITLE
      WRITE OUTPUT TAPE 6,98
      V=XDOT+WIND
      DUMMY=0.
      INDEX=1
      SIGTR=SIGT/57.3
      D17=(XCG-XL)/12.
      D1=(XCG-XN)/12.
      D3=(XM-XCG)/12.
      D6=(ZCG-ZN)/12.
      D8=(ZCG-ZM)/12.
      D2=(XCG-XB)/12.
      PM=.75*W
      PN=PM/5.
      I=0
6     CALL STABLE (PMT,SMT,10,PM,SMI)
      CALL STABLE (PNT,SNT,10,PN,SNI)
      CALL STABLE (PMTT,TIRMT,10,PM,TIRM)
      CALL STABLE (PNTT,TIRNT, 10,PN,TIRN)
      RN=(RNO-TIRN)/12.
      RM=(RMO-TIRM)/12.
```

```
      SM=SMI/12.
      SN=SNI/12.
      IF(KID) 7,7,8
7     STUFY=0.
      GO TO 9
8     STUFY=SNI
9     D7=(ZCG-ZB-STUFY)/12.
      R=RN-RM
      Q=D8-D6+SN-SM
      P=D1+D3
      SINT=(P*R+SQRTF(P*P*R*R+(Q*Q-R*R)*(P*P+Q*Q)))/(P*P+Q*Q)
      THR=ATANF(SINT/(SQRTF(1.-SINT*SINT)))
      COST=COSF(THR)
      Z1=(D6-SN)*COST-D1*SINT+RN
      Z2=(D8-SM)*COST+D3*SINT+RM
      Z=(Z1+Z2)/2.
      D8BAR=(Z-D3*SINT-RM)/COST
      D6BAR=(Z+D1*SINT-RN)/COST
      A1=D7*COST-D2*SINT
      A10=D3*COST-D8BAR*SINT
      A11=D1*COST+D6BAR*SINT
      TH=THR*57.3
      CALL STABLE (ALFALT,CLT,10,TH,CL)
      CALL STABLE (ALFAMT,CMT,10,TH,CM)
      ALIFT=RHO*S*V*V*CL/2.
      AMOM=RHO*S*V*V*CBAR*CM/2.+D17*COST*ALIFT
      SINB=(Z-A1)/D12
      BETAR=ATANF(SINB/(SQRTF(1.-SINB*SINB)))
      COSB=COSF(BETAR)
      TANB=SINB/COSB
      FCZ=FC*TANB
      FCP=FC/COSB
      PCBAR=D7*COSF(THR+BETAR)-D2*SINF(THR+BETAR)
      GF=W-ALIFT-TR*SINF(THR+SIGTR)+FCZ
      GM=AMOM+PCBAR*FCP-Z*UR*(2.*PM+PN)-TR*TARM
      PNA=(GF*A10-GM)/(A10+A11)
      PMA=(GF*A11+GM)/(2.*(A10+A11))
      IF(ABSF((PN-PNA)/PN)-.05) 10,10,13
10    IF(ABSF((PM-PMA)/PM)-.05) 15,15,13
13    PM=(PM+PMA)/2.
      PN=(PN+PNA)/2.
      I=I+1
      IF(I-50) 6,6,59
15    WRITEOUTPUTTAPE6, 96,Z,TH,DUMMY,PMA,PNA,DUMMY,V,DUMMY
      PM=PMA
      PN=PNA
```

```
      THR=TH/57.3
      COST=COSF(THR)
      SINT=SINF(THR)
      A2=D2*COST+D7*SINT
      DELT=DELT1
      ANEDGE=DEDGE+A2+D12*COSR-A11
      AMEDGE=ANEDGE+A10+A11
      AM=W/32.2
      P20=RHO*S/2.
      P21=P20*CBAR
      SIGTR=SIGT/57.3
      GAMDOT=0.
      GAMA=0.
      GAMAR=0.
      ALFAR=THR
      ZDOT=0.
      COSG=COSF(GAMAR)
      SING=SINF(GAMAR)
      THDOT=0.
      X=0.
      V=XDOT+WIND
      T=0.
20    CALL STABLE(PNTT,TIRNT,10,RN,TIRN)
      RN=(RNO-TIRN)/12.
      D6BAR=(Z+D1*SINT-RN)/COST
      SN=D6-D6BAR
      SNI=SN*12.
      IF(SNI) 21,21,18
18    CALL STABLE (SNT,PNT,10,SNI,PN)
      GO TO 22
21    PN=0.
22    CALL STABLE(PMTT,TIRMT,10,RM,TIRM)
      RM=(RMO-TIRM)/12.
      D8BAR=(Z-D3*SINT-RM)/COST
      SM=D8-D8BAR
      SMI=SM*12.
      IF(SMI) 32,32,23
23    CALL STABLE(SMT,PMT,10,SMI,PM)
      GO TO 31
30    DELT=DELT2
      PN=0.
32    PM=0.
31    A10=D3*COST-D8BAR*SINT
      A11=D1*COST+D6BAR*SINT
      CALL STABLE(ALFALT,CLT,10,ALFA,CL)
      CALL STABLE(ALFADT,CDT,10,ALFA,CD)
```

```
      CALL STABLE(ALFAMT,CMT,10,ALFA,CM)
      ALIFT=P20*V*V*CL
      DRAG=P20*V*V*CD
      AMOM=P21*V*V*CM+ALIFT*D17 [illegible]*COSF(ALFAR)
      SUMFX=TR*COSF(ALFAR+SIGTR)-DRAG-W*SING
     1+PM*PNK*(SING-UR*COSG)
     2+2.*PM*PMK*(SING-UR*COSG)
      SUMFZ=ALIFT-W*COSG+TR*SINF(ALFAR+SIGTR)
     1+PM*PNK*(COSG+UR*SING)
     2+2.*PM*PMK*(COSG+UR*SING)
      SUMMY=AMOM-TR*TA[illegible]+CK*THDOT*V
     1+PN*PNK*(A11-UR*Z)-2.[illegible]
      T=T+DELT
      IF(T-TMAX) 24,24,60
24    VDOT=SUMFX/AM
      V=V+VDOT*DELT
      GAMDOT=SUMFZ/(AM*V)
      GAMAR=GAMAR+GAMDOT*DELT
      SING=SINF(GAMAR)
      COSG=COSF(GAMAR)
      GAMA=GAMAR*57.3
      THDDOT=SUMMY/APIYY
      THR=THR+THDOT*DELT+THDDOT*DELT*DELT/2.
      COST=COSF(THR)
      SINT=SINF(THR)
      TH=THR*57.3
      ALFA=TH-GAMA
      ALFAR=ALFA/57.3
      THDOT=THDOT+THDDOT*DELT
      VX=V*COSG
      VZ=V*SING
      XDOT=VX-WIND
      X=X+XDOT*DELT
      Z=Z+VZ*DELT
      INDEX=INDEX+1
      IF(INDEX-50) 49,49,48
48    INDEX=1
      WRITE OUTPUT TAPE 6,89
      WRITE OUTPUT TAPE 6,88,TITLE
      WRITE OUTPUT TAPE 6,98
49    WRITE OUTPUT TAPE 6,96,Z,TH,GAMA,PM,PN,X,V,T
      IF(X-ANEDGE) 20,20,50
50    IF(X-AMEDGE) 21,21,30
59    WRITEOUTPUTTAPE6, 95
60     CONTINUE
      CALL EXIT
```

```
      GO TO 100
      END
0232
```

FORMAT FOR INPUT DATA

CARD	SYMBOLS	DEFINITION OF SYMBOLS	UNITS
1	PMT (1)	Axle stroke (1) associated with main gear load table	lbs.
1	PMT (2)	Axle stroke (2) associated with main gear load table	lbs.
	'	"	
	'	"	
1	PMT (5)	"	
2	PMT (6)	"	
2	PMT (7)	"	
	'		
	'		
2	PMT (10)	Axle stroke (10) associated with main gear load table	
3	SMT (1)	Main gear load (1) associated with main gear axle stroke table	in.
3	SMT (2)	Main gear load (2) associated with main gear axle stroke table	in.
	'	"	
	'	"	
3	SMT (5)	"	
4	SMT (6)	.	
4	SMT (7)	"	
	'	"	
	'	"	
4	SMT (10)	Main gear load (10) associated with main gear axle stroke table	
5	PNT (1)	Axle stroke (1) associated with nose gear load table	lbs.
5	PNT (2)	Axle stroke (2) associated with nose gear load table	lbs.
	'	"	
	'	"	
5	PNT (5)	"	
6	PNT (6)	"	
6	PNT (7)	"	
	'	"	
	'	"	
6	PNT (10)	Axle stroke (10) associated with nose gear load table	lbs.

FORMAT FOR INPUT DATA

CARD	SYMBOLS	DEFINITION OF SYMBOLS	UNITS
7	SNT (1)	Nose gear load associated with nose gear axle stroke table	in.
7	SNT (2)	Nose gear load associated with nose gear axle stroke table	in.
	'	"	
	'	"	
7	SNT (5)	"	
8	SNT (6)	"	
8	SNT (7)	"	
	'	"	
	'	"	
8	SNT (10)	Nose gear load associated with nose gear axle stroke table	in.
9	PMTT (1)	Main gear tire deflection (1) associated with main gear load table	lbs.
9	PMTT (2)	Main gear tire deflection (2) associated with main gear load table	lbs.
9	'	"	
	'	"	
9	PMTT (5)	"	
10	PMTT (6)	"	
10	PMTT (7)	"	
	'	"	
	'	"	
10	PMTT (10)	Main gear tire deflection (10) associated with main gear load table	lbs.
11	TIRMT (1)	Main gear load (1) associated with main gear tire deflection table	in.
11	TIRMT (2)	Main gear load (2) associated with main gear tire deflection table	in.
	'	"	
	'	"	
11	TIRMT (5)	"	
12	TIRMT (6)	"	
12	TIRMT (7)	"	
	'	"	
	'	"	
12	TIRMT (10)	Main gear load (10) associated with main gear tire deflection table	in.

FORTMAT FOR INPUT DATA

CARD	SYMBOLS	DEFINITION OF SYMBOLS	UNITS
13	PNTT (1)	Nose gear tire deflection (1) associated with nose gear load table	lbs.
13	PNTT (2)	Nose gear tire deflection (2) associated with nose gear load table	lbs.
	'	"	
	'	"	
13	PNTT (5)	"	
14	PNTT (6)	"	
14	PNTT (7)	"	
	'	"	
	'	"	
14	PNTT (10)	Nose gear tire deflection (10) with nose gear load table	lbs.
15	TIRNT (1)	Nose gear load (1) associated with nose gear tire deflection table	in.
15	TIRNT (2)	Nose gear load (2) associated with nose gear tire deflection table	in.
	'	"	
	'	"	
15	TIRNT (5)	"	
16	TIRNT (6)	"	
16	TIRNT (7)	"	
	'	"	
	'	"	
16	TIRNT (10)	Nose gear load (10) associated with nose gear tire deflection table	in.
17	ALFALT (1)	Angle of attack (1) associated with lift coefficient table	none
17	ALFALT (2)	Angle of attack (2) associated with lift coefficient table	none
	'	"	
	'	"	
17	ALFALT (5)	"	
18	ALFALT (6)	"	
18	ALFALT (7)	"	
	'	"	
	'	"	
18	ALFALT (10)	Angle of attack (10) associated with lift coefficient table	none

FORMAT FOR INPUT DATA

CARD	SYMBOLS	DEFINITION OF SYMBOL	UNITS
19	CLT (1)	Lift coefficient (1) associated with angle of attack table	degrees
19	CLT (2)	Lift coefficient (2) associated with angle of attack table	degrees
	'	"	
	'	"	
19	CLT (5)	"	
20	CLT (6)	"	
20	CLT (7)	"	
	'	"	
	'	"	
20	CLT (10)	Lift coefficient (10) associated with angle of attack table	degrees
21	ALFADT (1)	Angle of attack (1) associated with drag coefficient table	none
21	ALFADT (2)	Angle of attack (2) associated with drag coefficient table	none
	'	"	
	'	"	
21	ALFADT (5)	"	
22	ALFADT (6)	"	
22	ALFADT (7)	"	
	'	"	
	'	"	
22	ALFADT (10)	Angle of attack (10) associated with drag coefficient table	none
23	CDT (1)	Drag coefficient (1) associated with angle of attack table	degrees
23	CDT (2)	Drag coefficient (2) associated with angle of attack table	degrees
	'	"	
	'	"	
23	CDT (5)	"	
24	CDT (6)	"	
24	CDT (7)	"	
	'	"	
	'	"	
24	CDT (10)	Drag coefficient (10) associated with angle of attack table	degrees

FORMAT FOR INPUT DATA

CARD	SYMBOL	DEFINITION OF SYMBOL	UNITS
25	ALFAMT (1)	Angle of attack (1) associated with aero. moment coefficient table	none
25	ALFAMT (2)	Angle of attack (2) associated with aero. moment coefficient table	none
	'	"	
	'	"	
25	ALFAMT (5)	"	
26	ALFAMT (6)	"	
26	ALFAMT (7)	"	
	'	"	
	'	"	
26	ALFAMT (10)	Angle of attack (10) associated with aero. moment coefficient table	none
27	CMT (1)	Aero. moment coefficient (1) associated with angle of attack table	degrees
27	CMT (2)	Aero. moment coefficient (2) associated with angle of attack table	degrees
	'	"	
	'	"	
27	CMT (5)	"	
28	CMT (6)	"	
28	CMT (7)	"	
	'	"	
	'	"	
28	CMT (10)	Aero. moment coefficient (10) associated with angle of attack table	degrees

FORMAT (5E10.4)

FORMAT FOR BASIC INPUT DATA

CARD	SYMBOL	DEFINITION OF SYMBOL	UNITS
29	XCG	Fuselage station of airplane center of gravity	f.s.
29	ZCG	Water line of airplane center of gravity	w.l.
29	XN	Fuselage station of nose gear axle	f.s.
29	ZN	Waterline of nose gear axle at zero stroke	w.l.
29	XM	Fuselage station of main gear axle	f.s.
30	ZM	Waterline of main gear axle at zero stroke	w.l.
30	XB	Fuselage station of catapult bridle attachment point	f.s.
30	ZB	Waterline of catapult bridle attachment point (at nose gear stroke = 0 if applicable)	w.l.
30	XL	Fuselage station of aerodynamic reference point	f.s.
30	RNO	Nose gear undeflected tire radius	in.
31	RMO	Main gear undeflected tire radius	in.
31	RHO	Air density	$slugs/ft^3$
31	S	Wing area	$ft.^2$
31	CBAR	Mean geometric chord	ft.
31	D12	Catapult bridle length	ft.
32	FC	Catapult force at stroke end	lbs.
32	TR	Thrust	lbs.
32	W	Airplane weight	lbs.
32	UR	Coefficient of rolling friction	none
32	TARM	Thrust moment arm to c.g. (+ above c.g.)	ft.
33	XDOT	Ground speed	ft./sec
33	APIYY	Airplane pitch moment of inertia at c.g.	$slug\text{-}ft^2$
33	SIGT	Thrust angle	degrees
33	PNK	Nose gear load attenuation constant	none
33	PMK	Main gear load attenuation constant	none

FORMAT FOR BASIC INPUT DATA

CARD	SYMBOL	DEFINITION OF SYMBOL	UNITS
34	PK	Aerodynamic pitch damping	lb-sec^2
34	DELT1	Time increment before deck edge	sec
34	DELT2	Time increment after deck edge	sec
34	WIND	Wind velocity	ft./sec.
34	DEDGE	Distance from catapult shuttle at end of stroke to deck edge	ft.
35	TMAX	Maximum time	
	FORMAT (5E10.4)		
36	KID	Control number; if KID = 0 cat bridle attach point stationary, if KID > 0 cat bridle attach point moves with nose gear stroke	none
	FORMAT (I3)		

OUTPUT DATA

FORTRAN NAME	TITLE NAME	DEFINITION	UNITS
Z	Z	c.g. Height Above Deck	ft
TH	THETA	Airplane Pitch Attitude	degrees
GAMA	GAMMA	Flight Path Angle	degrees
PM	PM	Main Gear Load (One Gear)	lbs.
PN	PN	Nose Gear Load	lbs.
X	X	Horizontal Distance Traveled (x = 0 at Catapult Stroke End)	ft
V	VEL	Airspeed	ft/sec
T	TIME	Time (t = 0 at Catapult Stroke End)	sec

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13. ABSTRACT

A simplified method for predicting the catapult performance of a carrier-based airplane has been developed under Contract No. NOw 62-0197-t, Task Order No. 62-1, for the Bureau of Naval Weapons. The method consists of two parts; (a) the determination of airplane position at the end of the catapult power stroke and (b) the determination of the motion of the airplane subsequent to leaving the catapult. The method is oriented toward use of a small digital computer; however, the calculations could be performed with only the use of a desk calculator.

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